

The contrast transfer of periodical structures in a photographic emulsion developed with adjacency effects

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With 8 figures in the text

ABSTRACT

The adjacency effect is examined by the same method of contrast transfer as now often used, is particular so that a periodical sinusoidal line pattern is exposed with an optical system on a photographic emulsion. Herewith, remarkable differences in the contrast transfer functions of the emulsion occur between development when adjacency effects are rigorously avoided and when such are present.

The examination shows a maximal effect at 20–30 lines per mm. Even at 80–100 lines per mm an adjacency effect often exists.

General

By the developing of a photographic emulsion undesirable adjacency effects appear. If the developer is ineffectively stirred, it is the diffusibility of the chemical products between the liquid and the emulsion that produces the development. The result is an intensified density immediately inside the edge of a more strongly exposed portion, the so-called border effect, and a corresponding weakening outside the edge, the fringe effect. These typical adjacency effects only appear when the gradient and the level between the intensities of two differently exposed areas are sufficiently strong. An exact estimate of the strength of spectral lines and stars by a photometric method is, consequently, difficult to obtain. The first comprehensive investigation of this effect was made in a work by Eberhard [2] in 1912. The joint influence of the two effects, therefore, is known as the Eberhard effect.

Among later experimental works may be mentioned one carried out by Legreneur and Soullillon [7]. The comprehensive exposition by Mees is well-known [8].

The present examination, however, is made in connection with the determination of the light distribution function of photographic emulsions. In addition to apparatus and method of work, the use of the Fourier analysis by photographic emulsions produced without adjacency effect is described in an earlier publication [4]. This examination, consequently, joins directly the former.

The discontinuous exposure from one area to an adjacent area has been the basis of earlier examinations of the adjacency effect. The exposure may, for

instance, be effected at a straight edge, a slit or a hole. These contact exposures have appeared as isolated details against a homogeneous background.

The method of examination used here can be practically characterized as a special case of the Eberhard effect. The isolated exposed areas are replaced by a reproduction of a periodic sinusoidal line pattern [4], according to the function:

$$f_o(x) = 1 + C_o(N_k) \cdot \cos 2\pi N_k x \quad (1)$$

where N_k is a variable spatial frequency.

The contrast of the object is diminished by the optical arrangement to $C_o(N_k) \cdot |F_{\text{opt}}(N_k)|$ in the optical aerial image. Also the light diffusion in the emulsion causes a broadening of the light image, so that the latent image gets a still smaller contrast. If the emulsion is normally developed without disturbing side effects, a density is obtained which is evaluated in $I \cdot t$ values by the aid of an exposed density strip. It is this fictitious $I \cdot t$ image which is generally called the effective image according to:

$$f_i(x) = 1 + |F_{\text{tot}}(N_k)| \cdot C_o(N_k) \cdot \cos 2\pi N_k x. \quad (2)$$

The frequency N_k is maintained straight through the transmitting system. On the other hand, the amplitude of the sine pattern drops more and more so that the final contrast is:

$$F_{\text{tot}}(N_k) = F_{\text{em}}(N_k) \cdot F_{\text{opt}}(N_k). \quad (3)$$

In the earlier work it was shown that the transfer linearity is maintained right through all the elements between object and image. Thus, one can calculate the CT -function in the photographic reproduction. If, however, the photographic emulsion is developed so that adjacency effects appear, the sine shape of $f_i(x)$ is transformed and the sinusoidal line pattern get another structure in density. The extreme values of every period are not influenced in the same degree as adjacent parts. This is intimately connected with the action of the adjacency effect. The least and most exposed parts of the transmission curve (solid in Fig. 1) give at the evaluation an $I \cdot t$ -curve which has lower and higher extreme values than the corresponding sine curves (dotted in Fig. 1). This is a direct consequence of the ineffectivity of the stirring of the developer. Often there arises a transmission that becomes greater than that of the fog. This is confirmed by the microphotometry of the emulsion. Thus the chemical process has, from the physical point of view, a negative character.

A closer study of a microphotometrical curve shows certain peculiarities, e.g. transmission curves obtain the lowest values at $N \sim 14 - 18 \text{ mm}^{-1}$ and the highest at $N \sim 23 - 46 \text{ mm}^{-1}$. This indicates, without having to eliminate the influence of optics, that the border and fringe effects, probably depend on the varying distribution of the developing grains. But since the mean intensity of the object, the working point, lies on the same level during the whole experiment, the sine pattern has, consequently, changed its character.

One of the fundamental conditions for the Fourier calculation, namely linearity, drops out on reproduction with adjacency effect. In spite of this, a false Fourier calculation, which ignores non-linearity, has given valuable contributions to the

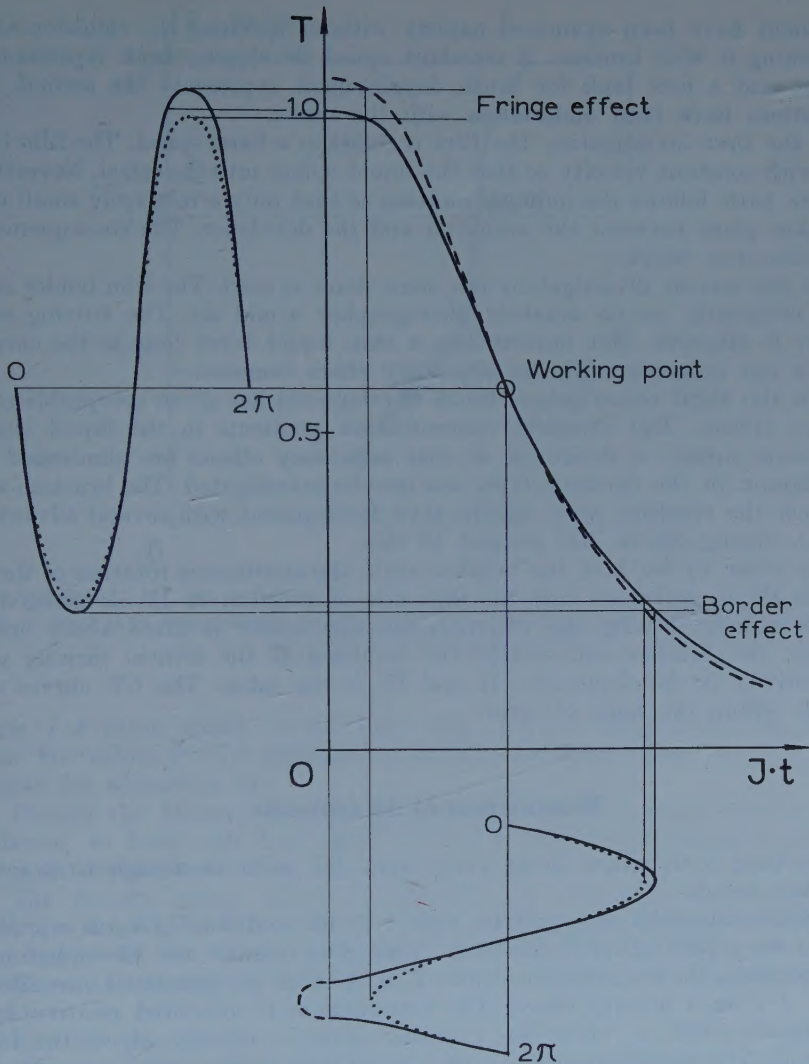


Fig. 1. Transmission T is a function of $I \cdot t$. Solid curve computed experimentally from a density strip. Dashed curve, theoretical density curve, constructed so that a curve with adjacency effect, on the left side, gives true $I \cdot t$ values. Below is a period in $I \cdot t$ values. Dotted curves represent a development free from adjacency effect.

solving of the extent of the adjacency effect. The adjacency effect is correlated to a factor $E(N)$ in the calculations.

Methods of development

The concentration gradients in the developer next to the emulsion surface have been systematically treated in four examinations. The photographic emulsion has been in water baths during the whole of the development. Two types of

development have been examined namely without touching the emulsion surface and touching it with brushes. A standard spiral developing tank represents the first type and a new tank for brush development represents the second. Four investigations have been undertaken with the tanks.

I. In the first investigation the film is rolled in a loose spiral. The film holder rotates with constant velocity so that the liquid comes into the spiral. Nevertheless the water bath follows the uniform rotation so that only a relatively small movement takes place between the emulsion and the developer. The consequence is a strong adjacency effect.

II. In the second investigation the same tank is used. The film holder is now rotated irregularly as an amateur photographer would do. The stirring of the developer is effective. But nevertheless a thin liquid layer close to the emulsion surface is not influenced [5]. An adjacency effect remains.

III. In the third investigation brush development has given acceptable results free from effects. The chemical concentration gradients in the liquid close to the emulsion surface is destroyed so that adjacency effects are eliminated. The light diffusion in the emulsion layer can now be investigated. The brushes, which only touch the emulsion very lightly, give development with several advantages. Clark [1], among others, has pointed to this.

IV. In order to see how the brushes work, the continuous rotation of the film holder in III is varied so that the direction of rotation in IV is changed two times per minute. During the variation the film holder is lifted about one cm. Otherwise, the brushes can scratch the emulsion at the critical turning point. The effectivity in developments III and IV is the same. The *CT* curves agree very well within the limit of error.

Measurement of the contrasts

The method is described in an early work [4], so it is enough to point out only a few details.

A periodic sinusoidal line pattern with a given contrast $C_o(N_k)$ is reproduced by optics on a photographic emulsion. After development and microphotometry of the emulsion, the transmission values T of the film are translated into effective intensity $I \cdot t$ by a density curve. The transmission is measured relative to the fog. Naturally, this is when the exposure gives a density above the fogged background. The measurements are thus valid independent of the support of the emulsion. The fog corresponds, therefore, to the transmission $T = 1.0$ and the intensity $I \cdot t = 0$.

For every exposed frequency N_k the contrast $C_o(N_k) \cdot |F_{\text{tot}}(N_k)|$ of the effective image is obtained. Division, point-by-point, by $|F_{\text{opt}}(N_k)|$ of the optics gives generally

$$C_o(N) \cdot |F_{\text{em}}(N)| = \frac{C_o(N) \cdot |F_{\text{tot}}(N)|}{|F_{\text{opt}}(N)|} \quad (4)$$

Division by $C_o(N)$ gives the transform $|F_{\text{em}}(N)|$.

The problem is, however, different if an adjacency effect appears. The border-effect influences the sine curve, so that the minimum transmission value T_{min}

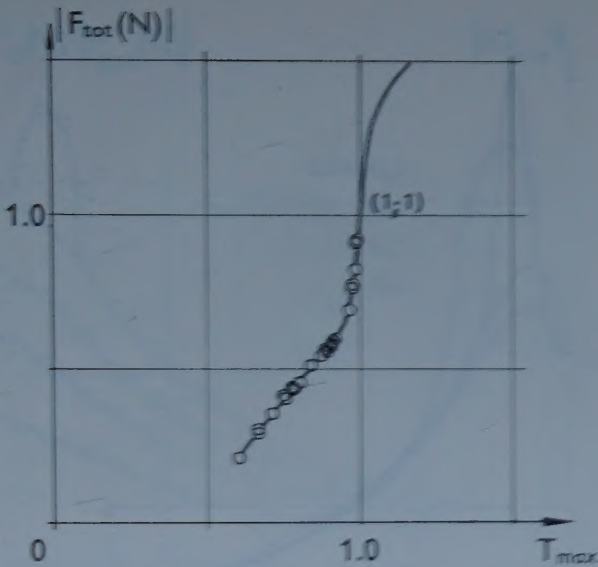


Fig. 2. Values of $|F_{\text{tot}}(N)| < 1$ determine $|F_{\text{tot}}(N)|$ as a function of T_{max} . This curve is extended so that it is symmetrical about point $(1.0; 1.0)$. $T_{\text{max}} > 1$ is valued with extension at $|F_{\text{tot}}(N)| > 1$. Development II.

obtains $I \cdot t$ value which is too high. (Fig. 1.) The fringe effect has contrary action. For values $T > 1.0$ difficulties come into the calculations.

Points for discussion are:

a. Though the linearity is spoiled on arrival of the adjacency effect, a Fourier calculation, in form, has been made. This is a logical starting-point for experiment with developments free from adjacency effect.

b. The density curve, which is obtained from a density strip is used, even though the translated $I \cdot t$ values are wrong. Only $T_{\text{max}} < 1.0$ is treated directly in this manner. If the border and fringe effects were to be translated into true $I \cdot t$ values, a theoretical density curve would replace the experimental one (Fig. 1).

c. By this process $T > 1.0$ becomes automatically $I \cdot t < 0$. Then the photographic image gets values $C_o(N) \cdot |F_{\text{tot}}(N)| > 1.0$, appreciably greater than the contrast of the object $C_o(N)$.

A standard calculation of the contrast has the result that the mean intensity of the image (the working point) will move. To avoid this, the following method is applied. The calculations consider the greater effect, the fringe effect shows on the extreme value T_{max} . The values $|F_{\text{tot}}(N)| < 1.0$ are marked in a diagram as ordinate and the associated T_{max} as abscissa (Fig. 2). Thereafter, this curve is extended so that it is symmetrical about the point $(1.0; 1.0)$. The extended curve gives, for every $T_{\text{max}} > 1.0$, a value $|F_{\text{tot}}(N)| > 1.0$. It must, however, be underlined that this assumption has ad-hoc features, but can be regarded as a tolerable approximation, because the working point is kept in its place.

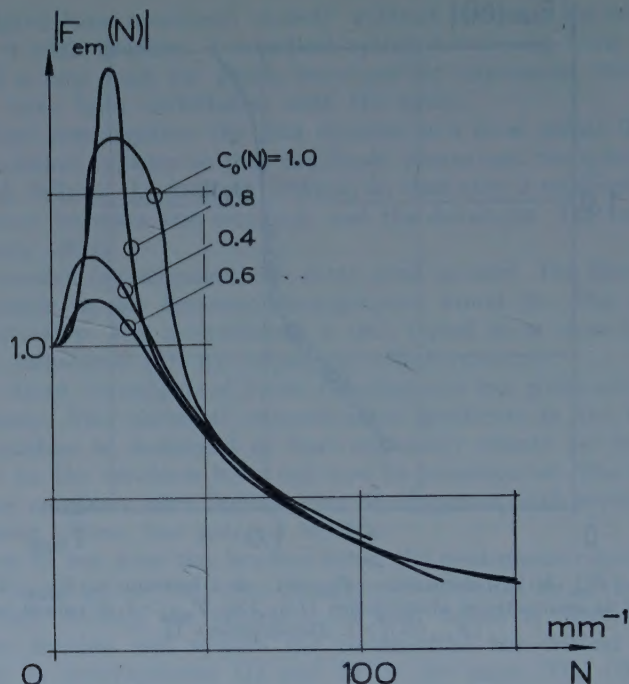


Fig. 3. $|F_{em}(N)|$ is determined at different contrast $C_o(N)$ of the object. Maximum of adjacency effects is shifted to larger N , when $C_o(N)$ increases. Development II.

$|F_{em}(N)|$ curves. A discussion

In the investigation of the light distribution function in the photographic emulsion, the development must be free of adjacency effect. The step progress of developments from near maximal adjacency effect to a good development free from this effect is reported here. The investigation is done on 35 mm film, Kodak Microfile Pan. The development D 158 is working for 3 minutes at 20°C.

As light source, a tungsten band lamp is used. The light is filtered by using a coloured glass filter. The transmission maximum is at $\lambda = 546 \text{ m}\mu$ and the half-value width 35 m μ . The light intensity and the mean density are varied. The greatest difference is between the two developments in the spiral developing tank. The mean density for the four investigations is 0.24, 0.39, 0.49 and 0.52. But as the *CT* curves of an emulsion are independent of moderate variation of the mean density the variation will not influence the result.

The investigation is done so that the contrast $C_o(N)$ of the object is constant, independent of N during the exposure of the line pattern. $C_o(N)$ is varied between 0.4 and 1.0. Every exposure gives a curve $C_o(N) \cdot |F_{em}(N)|$ (eq. 4) as a result. In Fig. 3 four curves are obtained with the development II, when $C_o(N) = 0.4, 0.6, 0.8$ and 1.0. Development IV gives the curves in Fig. 4. The *CT* curves are here represented by $C_o(N) \cdot |F_{em}(N)|$, for $|F_{em}(N)|$ is here independent of $C_o(N)$. Only light diffusion in the emulsion is thus represented in

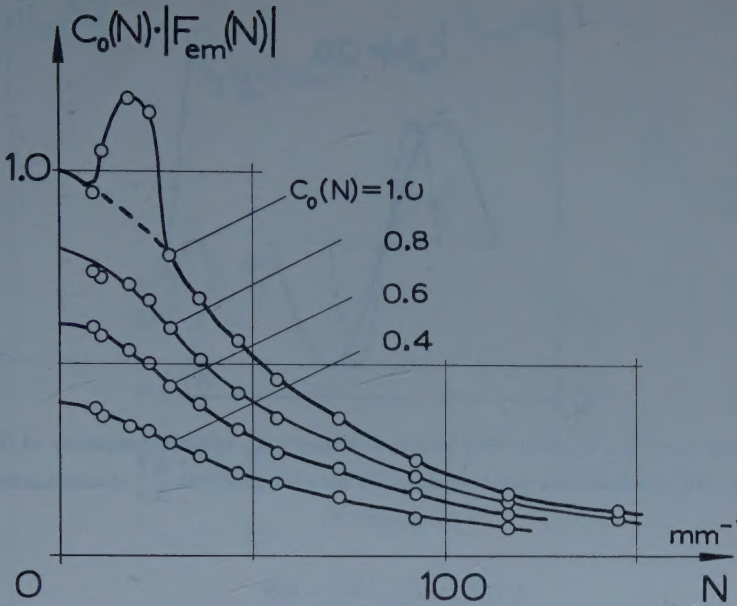


Fig. 4. Four curves represent $C_o(N) \cdot |F_{em}(N)|$. Upper curve has $C_o(N) = 1.0$. No adjacency effect. Development IV.

the curves. The three points, where $1.0 \cdot |F_{em}(N)| > 1.0$, may depend on the technique of the measurement and evaluation, inhomogeneities in the emulsion or adjacency effects. The hump can be compensated for by the interpolated curve, dashed in the figure. A characterizing feature of the curves is indeed that $|F_{em}(N)|$ decreases continuously when N increases. In development II, however, another type of curves appears (Fig. 3). Every curve has a maximum, a hump, within the low frequency region, $10 \text{ mm}^{-1} < N < 30 \text{ mm}^{-1}$. First and foremost, the various effectivities of the two developing tanks distinguish the investigations. Different developing methods destroy chemical concentration gradients in different degrees. The spiral developing tank is working least effectively. The adjacency effect also gives $|F_{em}(N)|$ curves higher than usual, $|F_{em}(N)| > 1.0$.

The effect is larger when the exposed contrast $C_o(N)$ is increased. The explanation is that a higher amplitude of the illumination gives a steeper gradient at the mean intensity. The chemical concentration gradients grow powerfully. The figure 3 shows how the maximum of the adjacency effects is shifted to higher N values, when $C_o(N)$ increases. The gradient at mean intensity also grows steeper when N becomes higher (Fig. 5).

Several reasons contribute to the fact that the adjacency effects at last die out, when N increases more and more. The gradient at mean intensity of the object certainly increases. But, at the same time the contrast of the image decreases because of the optics and the emulsion. It is true that the influence of the optical system can be eliminated by numerical calculations. But the CT value of the optics decreases continuously when N increases. For $N > 100 \text{ mm}^{-1}$, the line pattern of the optical aerial image almost always have contrasts

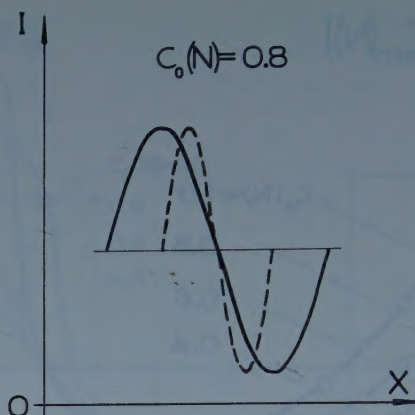


Fig. 5. Solid sine curve has double period length, therefore only half the frequency of the dashed curve. Curves will geometrically show connection between gradient $\frac{\Delta I}{\Delta x}$ at mean intensity and frequency N .

$$C_o(N) \cdot |F_{\text{opt}}(N)| < 0.8.$$

The region of the investigation is essentially limited by this fact. An additional reason, why the effect dies out, is that the distance between the lines becomes smaller, when N increases. The chemical work in the emulsion at the repeated lines prevents chemical concentration gradients to build up.

Both the periodicity and the geometry of the line pattern, in which the sine curves become steeper when N increases, result in differences between this investigation and that of Legreneur and Soullillon [7]. Their exposures of holes gave maximal Eberhard effect when the diameter was 0.1 mm. The maximum effect in this investigation is when $N = 20 - 30 \text{ mm}^{-1}$ and $C_o(N) > 0.8$.

Exposures at different values of $C_o(N)$ give interesting details of the determined $|F_{\text{em}}(N)|$ curves (Fig. 3). The dimensions of the humps vary when the contrast $C_o(N)$ varies. The adjacency effect is not a linear effect. But the linearity seems to exist when $N > 50 \text{ mm}^{-1}$. In this region the four curves of $|F_{\text{em}}(N)|$ have the same position. Probably the adjacency effect does not exist when the distance between two lines is too small.

How $|F_{\text{em}}(N)|$ is dependent on the exposed contrast $C_o(N)$ of the object at fixed frequencies N and on different developments is illustrated in Fig. 6. A single curve shows $|F_{\text{em}}(N)|$ as a function of $C_o(N)$, when N is parameter. Development I shows how difficult it is to draw a limit of the extent of the adjacency effect. The region over the dashed-dotted line signifies a development where it is present. The series of developments shows how a more effective development shifts the "limit" upwards. At the same time, the adjacency effect deteriorates. The curves become more even and horizontal. $|F_{\text{em}}(N)|$ will be independent of $C_o(N)$.

Comparisons between the *CT* curves also show how the dimensions of the hump become smaller when the developments give smaller adjacency effects (Fig. 7). The curves I and II represent not only light diffusion in the emulsion, but also

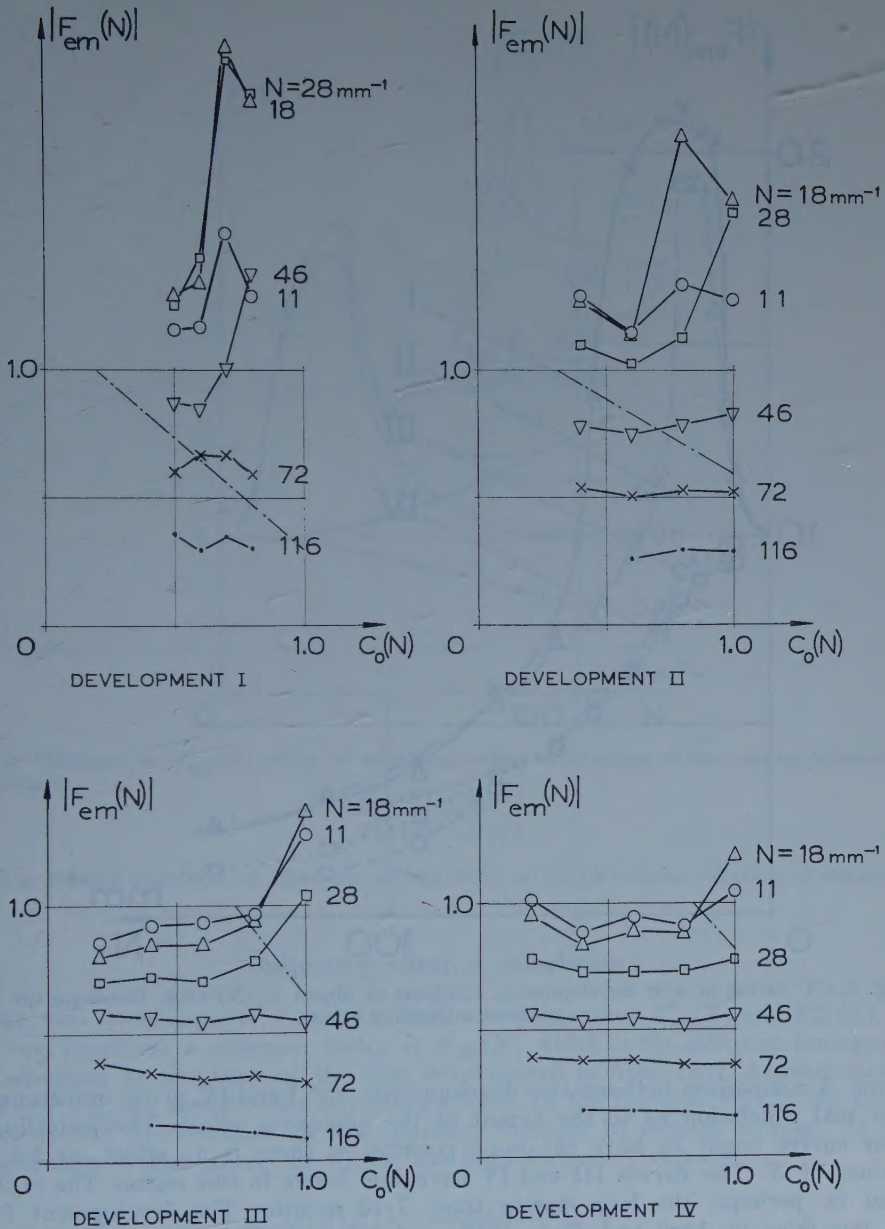


Fig. 6. $|F_{em}(N)|$ is a function of $C_0(N)$. The frequency N is parameter. Functions are obtained from similar curves in Fig. 3. Region free from adjacency effect is below dashed-dotted line. More effective development shifts this "limit" upwards.

an overlying adjacency effect. When $N > 75 \text{ mm}^{-1}$, there is probably no such effect. The brush development, however, makes $|F_{em}(N)|$ free from adjacency effect. The difference between development III and IV is within the limit of

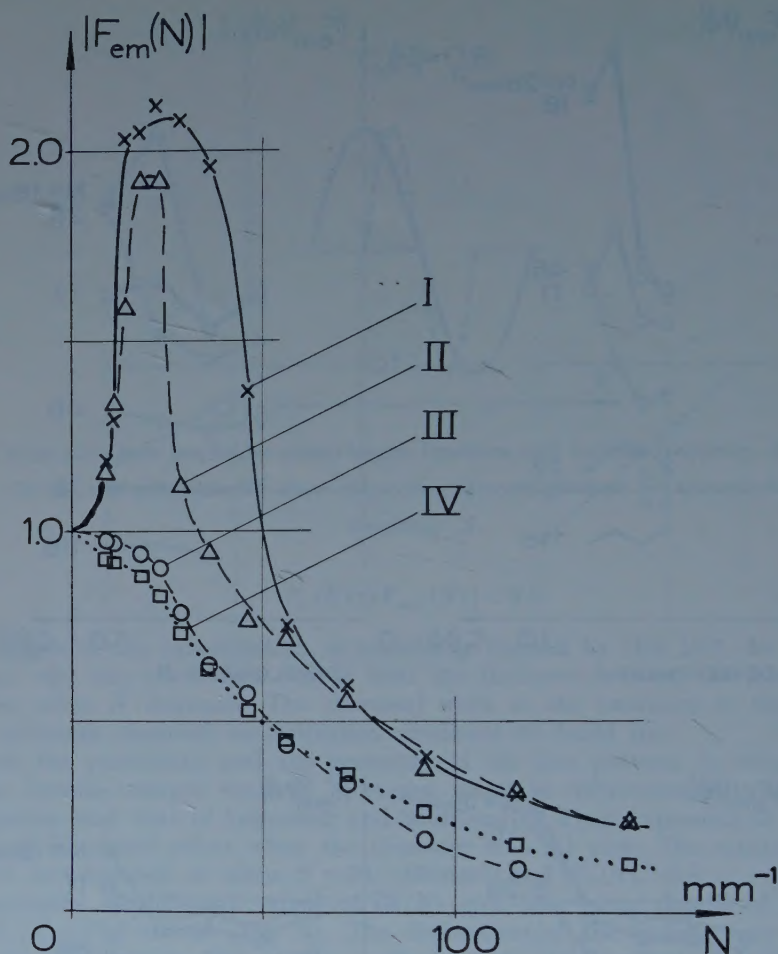


Fig. 7. *CT* curves of four developments. Contrast of object $C_o(N) = 0.8$. Development I has greatest adjacency effect.

error. A comparison between two developments, e.g. I and IV, gives, unfortunately, not real conclusion as to the extent of the adjacency effect. Theoretically, the four curves ought to have the same position, if there is no effect, as for high values of N . The curves III and IV have low levels in this region. The explanation is, perhaps, the long storing time, 7–10 months. The development I and II was done in April and May, 1957, and III and IV in December, 1957 and February, 1958. During the storage time the high frequency region of $|F_{em}(N)|$ probably deteriorated first. (This will be calculated in the next chapter.) The used emulsion ought not to have been exposed after October, 1957.

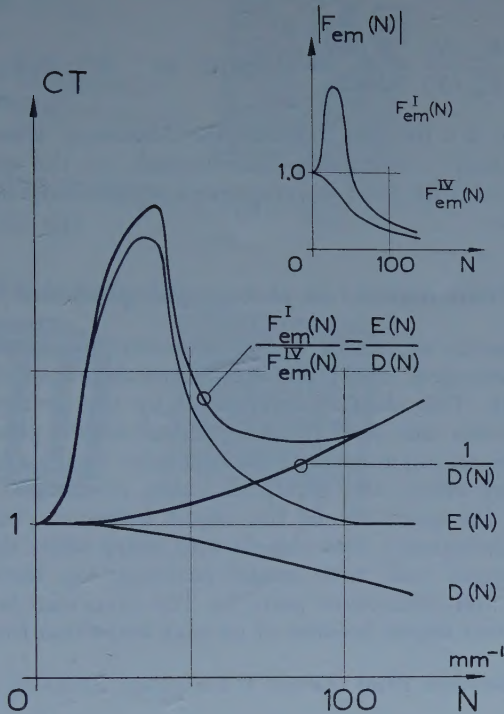


Fig. 8. Influence on $F_{em}(N)$ curve of adjacency effect and storage of film can be determined by division

$$\frac{F_{em}^I(N)}{F_{em}^{IV}(N)} = \frac{E(N)}{D(N)}.$$

$E(N)$ is Fourier transform of adjacency effect. $D(N)$ of $F_{em}^{IV}(N)$ means influence of storage.

Adjacency effect. A calculation

The two developments I and IV have the transforms $F_{em}^I(N)$ and $F_{em}^{IV}(N)$. In the two functions a common factor is $F_{em}(N)$ which is the diffusion function of the emulsion at the time of the first development in April 1957. Another factor, $E(N)$ of $F_{em}^I(N)$ signifies the adjacency effects. In the function $F_{em}^{IV}(N)$ the factor $D(N)$ is the deterioration of the emulsion through 10 months storage. As the deterioration works above all within the high frequency region,

$$D(N) = (1 + \text{constant} \cdot N^2)^{-1}$$

In this example, the constant = $0.52 \cdot 10^{-4}$. (Fig. 8.)
Thus in mathematic formulas:

$$F_{em}^I = E(N) \cdot F_{em}(N)$$

$$F_{em}^{IV} = D(N) \cdot F_{em}(N)$$

Division gives:

$$\frac{F_{em}^I(N)}{F_{em}^{IV}(N)} = \frac{E(N)}{D(N)} = (1 + 0,52 \cdot 10^{-4} \cdot N^2) \cdot E(N)$$

For the frequencies $N < 100 \text{ mm}^{-1}$ where the adjacency effect exists, $E(N) > 1$. The limit, $N = 100 \text{ mm}^{-1}$, is diffuse. This depends on the conditions of the investigations. $E(N) = 1.0$ at good developments without adjacency effects, as with brush developments.

Some remarks on photographic photometry

On exposing different structures of the intensity, the amplitude $|F_{em}(N)|$ can often represent, unchanged, one kind of emulsion-developer system. But, as well, a phase shift results. This shift is determined by the geometrical shape of the image. Eyer has shown this shift to be dependent on the phase of exposures of a straight edge, where an asymmetrical photographic image appears [3]. On developing with adjacency effect, the amplitude, also, is changed in a manner difficult to control, as the geometry of the object influences the amplitude. Thus, with photographic photometry, test objects with sharp edges should be replaced by those which correspond well with actual patterns, e.g. those in spectral lines, interference fringes and diffraction patterns. The sinusoidal line pattern is particularly suitable as a test object because of its easy transition from light to darkness.

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